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RETURN OF EXPERIENCE FROM CONTINUOUS PD MONITORING OF ROTATING MACHINES

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Abstract *– The experience from continuous partial discharge monitoring to assess the condition of generator stator winding insulation is presented. The case studies are related to monitoring of hydro and turbo generators of different rated power from 140 MVA to 1160 MVA. The advanced features for elimination of disturbances and for separation of different types of insulation defects based on synchronous, multi-channel and multi-frequency techniques are shown. The examples of data evaluation are described in detail and the use of the automated PD pattern recognition system is also discussed.*

Palabras clave: Monitoring – Partial Discharges – Rotating Machines – Generator – Online Diagnosis – Condition Based Maintenance

1 INTRODUCTION

On-line, continuous partial discharge (PD) monitoring has been used for decades to assess the condition of a generator stator winding insulation system. Modern digital monitoring equipment, with advanced hardware and software capabilities, has allowed improving insulation diagnostics by means of PD analysis. The determination of type of the defect and its severity is easier at machine normal operating conditions and the results of the data evaluation are more accurate. This helps maintenance engineers set up an effective condition based maintenance program [1].
A previous paper by the authors described in details the elements of a modern PD diagnostic system [2]. This paper deals with the aspect of interpretation of PD monitoring data, coming from practical cases studies. Four cases related to machines with different insulation technology as well as different rated voltages and powers are considered:

- turbo generator of 1160 MVA and 27 kV
- turbo generator of 436 MVA and 20 kV
- turbo generator of 180 MVA and 16.5 kV
- hydro generators of 140 MVA and 16.5 kV

The PD data are synchronously acquired from all three phases and multi-channel techniques for noise elimination and PD source separation are applied to make accurate insulation conditions assessment. The automated pattern recognition system is also used to make the analysis faster and with limited need of human expert involvement.

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2 SYSTEM CONCEPT

The concept of a modern on-line continuous monitoring system is presented in Fig. 1 [2]. The signals from PD sensors are synchronously acquired in a three-channel data acquisition unit, which performs pre-processing of the raw data to remove disturbances and to determine PD characteristics. The monitoring data can be acquired in two modes, permanent and periodic, which are flexible and can be defined by the user. During normal operation only data from periodic mode are stored to avoid overloading of the data base. Example of data from periodic mode is shown in the PD trend diagram in Figure 2. For each measurement, scalar values (apparent charge, repetition rate of the pulses, AC voltage phase and the absolute time) and phase resolved partial discharge (PRPD) patterns are saved.
In case of an alarm (threshold violation), data acquired in permanent mode will be automatically stored and displayed in the trend diagram. Thus, only the most relevant monitoring data is kept for analysis while redundant information is discarded.

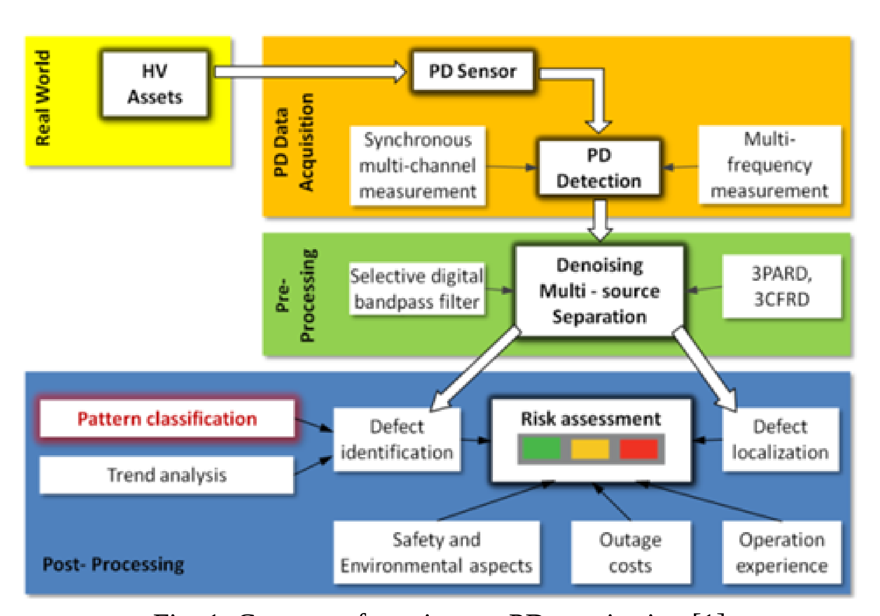


Fig. 1. Concept of continuous PD monitoring [1]

3 CASE STUDY: TURBO GENERATOR 1160MVA, 27kV

The 1160 MVA, 27 kV turbo generator was put in operation in 1998 and in 2012 was taken out of service for regular maintenance.
The on-line PD monitoring system was installed during the outage and it started immediately collecting data when the generator was put back into operation. It can be seen in the three phase PD trend diagram (Fig. 2) that the PD level decreases after start up. After the conditioning time of two months a data processing was performed with the support of an automated pattern classification system. The accuracy of automatic data evaluation depends on the efficiency of preliminary separation of different PD sources and on effective suppression of disturbances and background noise. To achieve this, synchronous multi-channel evaluation techniques were applied [3].
The synchronous multi-channel PD evaluation technique (3PARD diagram) visualizes the relationship between the amplitudes of a single PD pulse in one phase and its crosstalk generated signals in the other two phases. By repetition of this procedure for a large number of PD pulses, PD sources within the test object, as well as outer noise, appear as clearly distinguishable clusters (concentrations of dots) in the 3PARD diagram [2,3,4]. Each cluster from the 3PARD can be selected individually and, by means of a back transformation algorithm converted into a PRPD pattern, thus making possible the identification of separate PD sources. An example of the 3PARD separation procedure is presented in Fig. 3. Three clusters from the 3PARD diagram are analyzed and their back transformation to PRPD pattern is performed. At the end the verification of the identified type of the defect is performed with an automated pattern classification application. It is based on

probabilistic (pattern recognition) and deterministic (knowledge-based analysis) approaches [3,4]. The automatically generated report is presented in Fig. 4.



Fig. 2. Three phase PD trend diagram

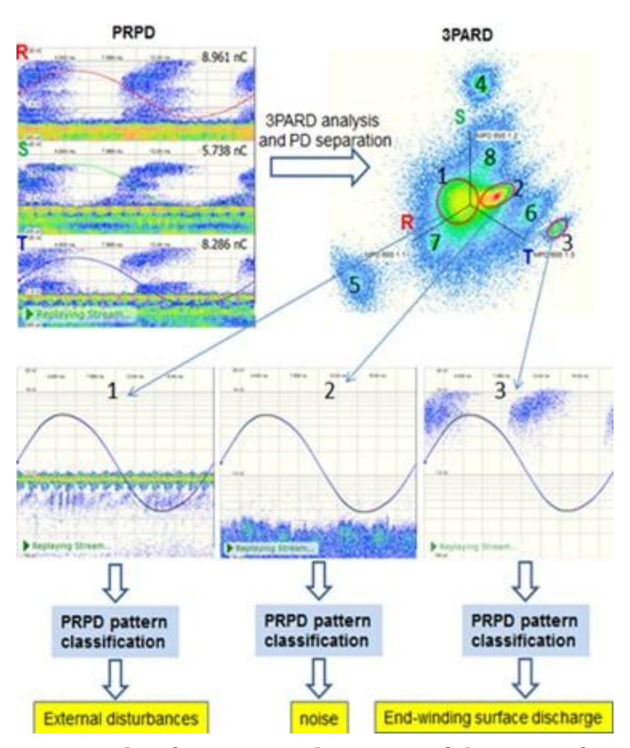


Fig. 3. An example of automatic diagnosis of the state of insulation

In Fig. 3, the external disturbances (cluster 1) and background noise (cluster 2) are separated from internal PD like phenomena. The pattern of cluster 3 shows surface discharges in the end winding area of the phase T. Patterns of similar defect are identified by analyzing clusters 4 and 5.

Back transformation of clusters 6-8 has also been performed. Automated pattern classification was applied for the PRPD pattern corresponding to cluster 6 and the report is presented in Fig. 4.

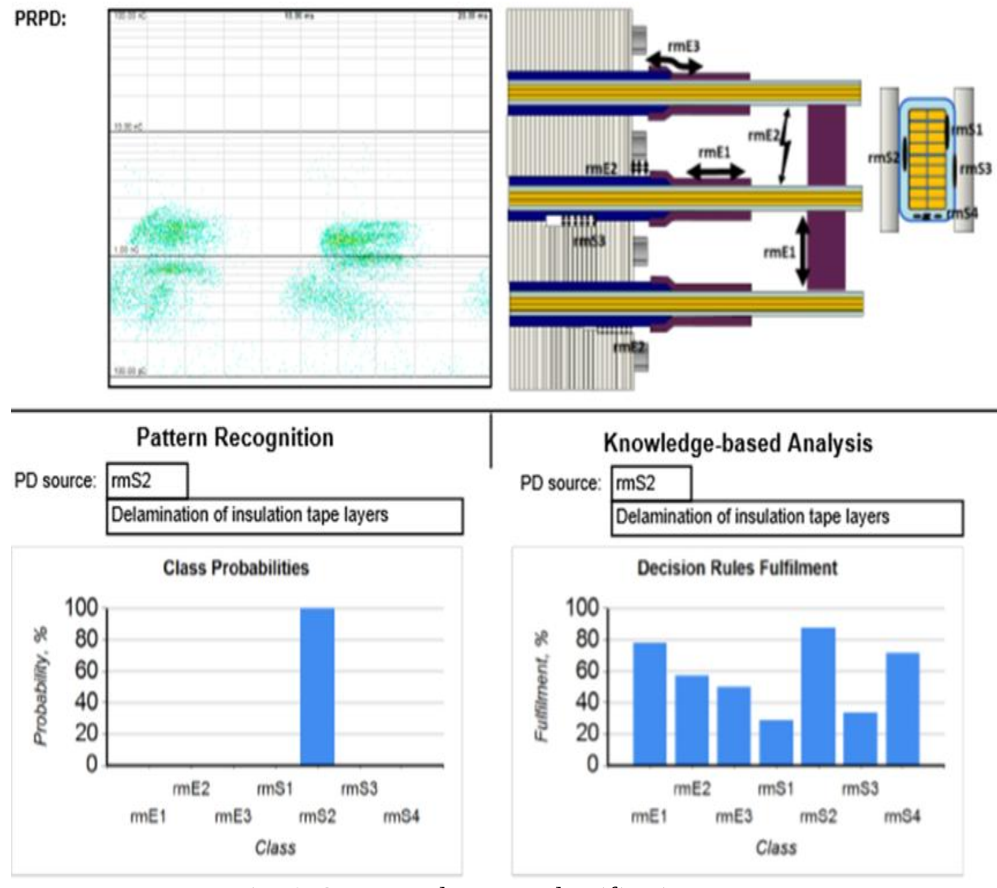


Fig. 4. Automated pattern classification report

According to the automatically generated report this pattern shows delamination of the insulation layers (class rmS2 – table 1). Similar data evaluation procedure was applied to PRPD patterns of clusters 7 and 8. The findings – reason for the PD activity evidenced by all clusters - are presented in Table I. The defects classes are nominated as in [5].

TABLA I. NORMAS SOBRE TÍTULOS
DE FIGURAS Y TABLAS

Defect´s class	Defect´s type
rmS1	Discharges in micron cavities
rmS2	Delamination of the insulation layers
rmS3	Delamination of the insulation on the copper side
rmS4	Delamination of the insulation on the core side
rmE1	End-winding surface discharge (tracking)
rmE2	End-winding surface discharge (because of insufficient space)
rmE3	Discharge between corona protection and stress grading layers

4 CASE STUDY: TURBO GENERATOR 436 MVA, 20 KV

On-line PD monitoring is installed on twin 436 MVA, 20 kV turbo generators, manufactured in 2007. The architecture of the monitoring system is shown in Fig. 5. Installed PD sensors are 1.1nF coupling capacitors. Another key element in the separation of PD sources from each other and from the background noise is the digital band-pass filter of the acquisition unit. Center frequency and bandwidth can be freely chosen in the range from dc up to 30 MHz (with a selectable filter bandwidth from 9 kHz up to 3 MHz) to avoid disturbances and to reach an optimal signal-to-noise ratio (SNR), even under noisy on-site conditions. In this case the PD measurements in the Acquisition Unit are set to a center frequency of 1 MHz and bandwidth of 300 kHz in order to get an optimal SNR.

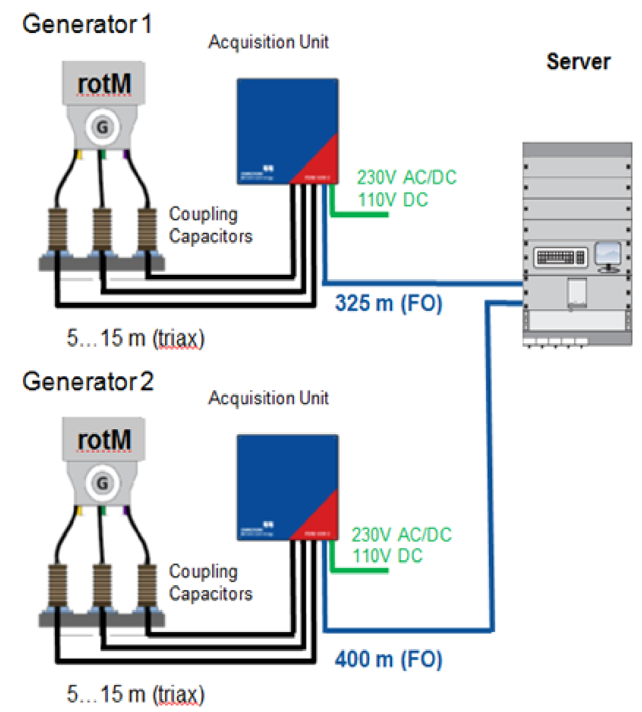


Fig. 5. Architecture of the on-line PD monitoring system

The start-up process of Generator 2 was monitored and in Fig. 6 the charge variation (green curve) during the increase of the voltage (red curve) is shown. The increase of PD activity can be correlated to the changes in load conditions (zones 2 and 3). The PD value increased from a few pC (background noise level) to 3.7 nC (Zone 2) and then to 5.7 nC (Zone 3) when the machine was at full load. The displayed voltage value is measured at the input to the acquisition unit. To get the real voltage value on the bus bar these values have to be multiplied by a divider factor of about 1000.

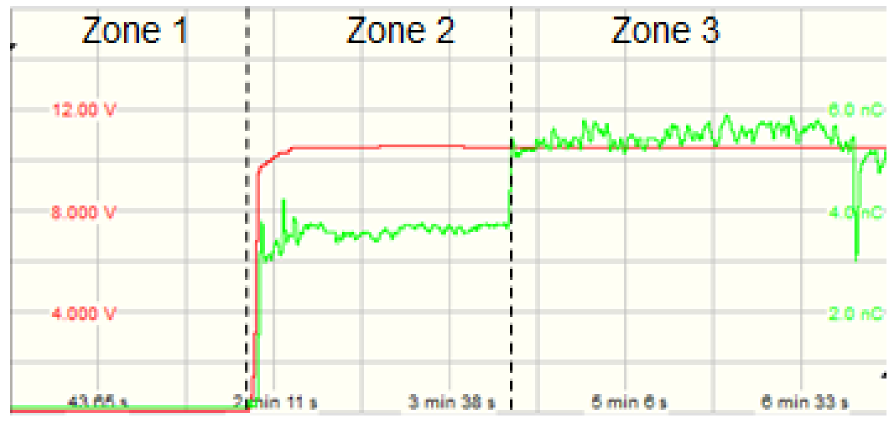


Fig. 6. PD trend during the start-up process

The three phase PRPD pattern of zone 3 is presented in Fig. 7-(a). The 3PARD feature was applied to identify PD defects in the PRPD diagram. The back transformation of cluster 1 from the 3PARD diagram was performed (Fig. 7-(b)) and the equivalent PRPD pattern is presented in Fig. 7-(c). This pattern has similarities with those generated by surface discharge in the end winding area, with the highest amplitude in phase S. The moisture contamination of the insulation surface during the outage might be one of the reasons for this type of PD. It should diminish with the operation time of the machine. The PD activity should remain under control. Clusters 2-4 from 3PARD diagram were discarded as they do not originate from the insulation system of the generator.

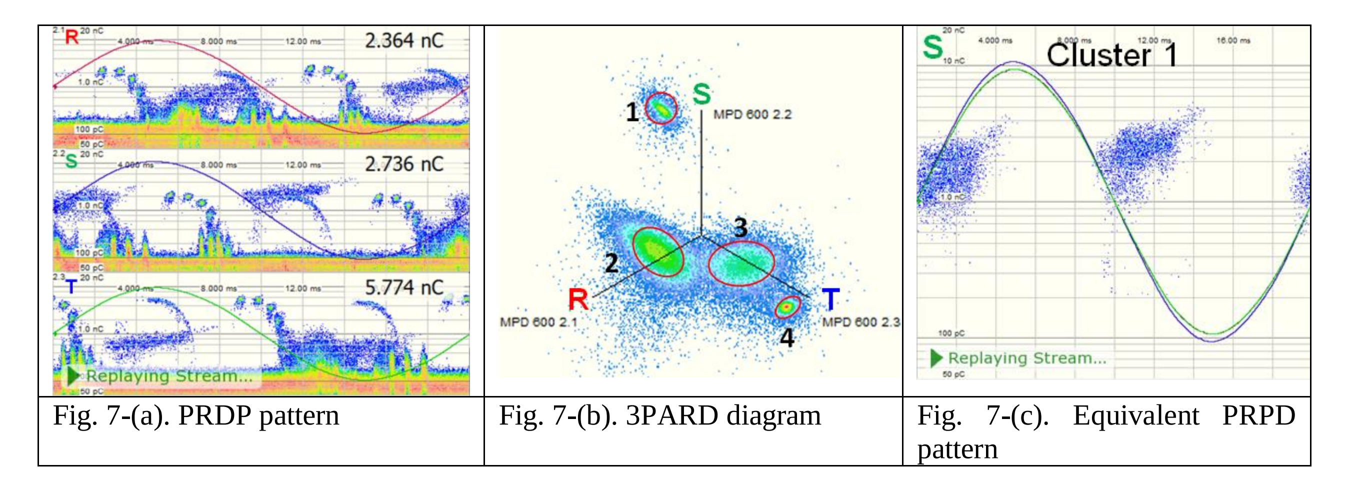


Fig. 7-(a). PRDP pattern	Fig. 7-(b). 3PARD diagram	Fig. 7-(c). Equivalent PRPD pattern

5 CASE STUDY: TURBO GENERATOR 180 MVA, 16.5 KV

This case study shows an example where preventive maintenance activity was triggered by the results from on-line PD monitoring. The device under monitoring is a 180 MVA turbo generator. Fig. 8 shows the three phase PD trend diagram and the PRPD patterns and 3PARD diagrams saved under each measured value.

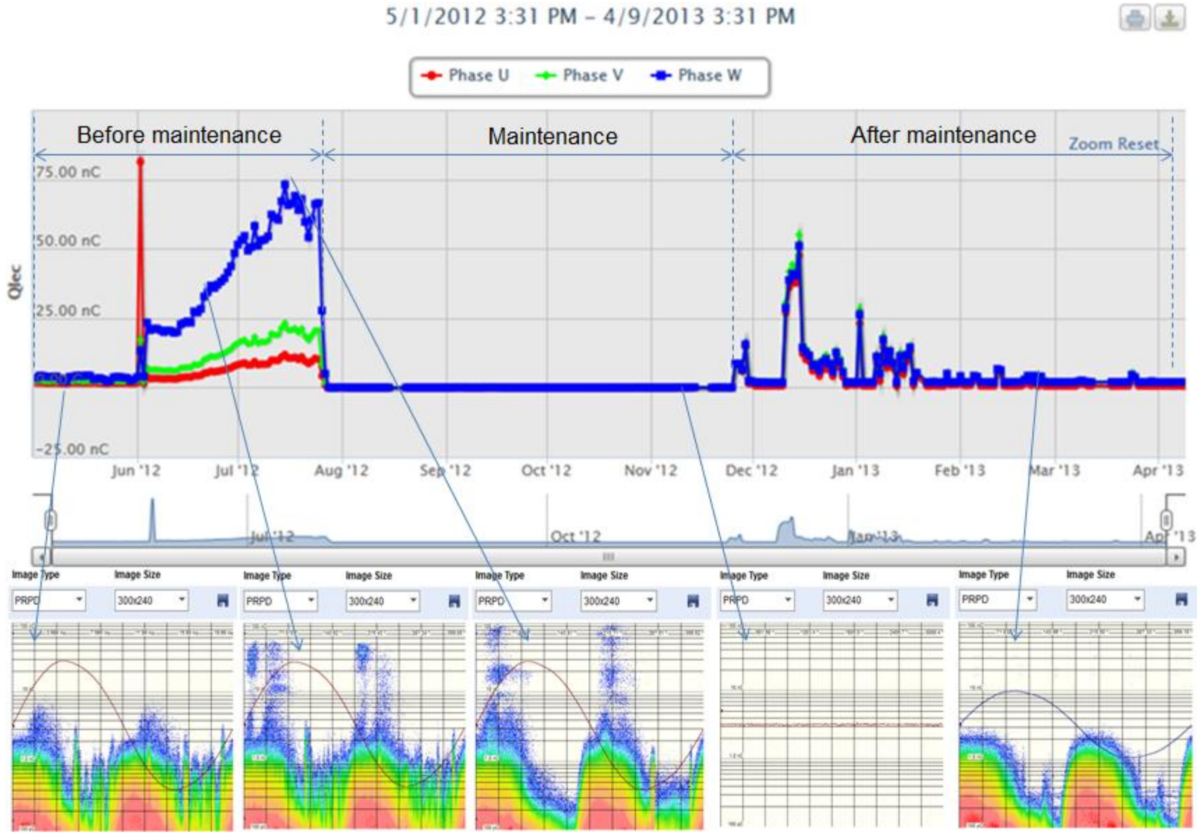


Fig. 8. Three phase PD trend and PRPD patterns before and after maintenance

According to the trend diagram, the increase of the PD signal in phase W (blue trend) from 20 nC to 75 nC within two months (June – August) was noticed. By analyzing the PRPD patterns within this time interval, the increase of PD activity generated by surface discharge in the end winding area was suspected. The separated PRPD pattern of this PD source is presented in Fig. 9.

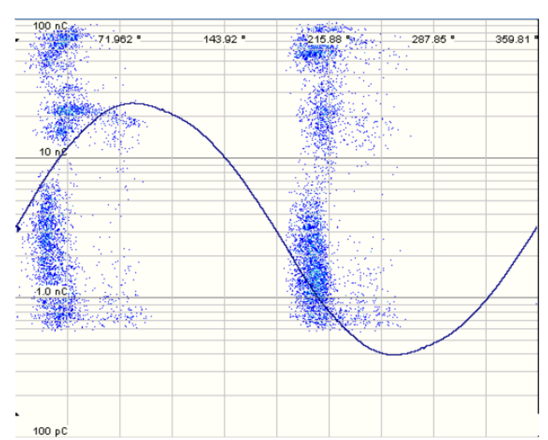


Fig. 9. PRPD pattern showing end winding surface discharge separated using 3PARD

Consequently, the generator was taken out of service for further investigations. The high concentration of surface contaminants was confirmed as one of the causes of the steep increase of discharge activity. During the maintenance activity the end section of the stator windings was cleaned and no more surface discharges were detected, see Fig. 8 (after maintenance section). Based on the PD results obtained before and after the maintenance of the machine, the effectiveness of the maintenance program can be evaluated and the time when the generator has to be taken out of service for maintenance can be decided.

6 CASE STUDY: HYDRO GENERATOR 140 MVA, 16.5 KV

On line PD monitoring was installed on eight identical hydro generators into operation since 1987. Preventive maintenance was triggered by the high PD values recorded at one of these machines (G1). By analysing the three phase PD trend diagram of G1 (Fig. 10) over three months, the increase of the PD level in phase S was observed (yellow trend). This indicated the existence of a PD source in this phase. Furthermore, data post-processing and automated pattern classification were applied in order to find the source of the high PD amplitude signal. The PD level is measured using 1.1 nF coupling capacitors and the digital filter was set to center frequency of 3 MHz and frequency bandwidth of 300 kHz. The three phase PRPD pattern was analyzed and the 3PARD tool was applied to separate all PD sources from each other and from the background noise. Fig. 11 shows the separation of the main PD source in phase S from background noise.

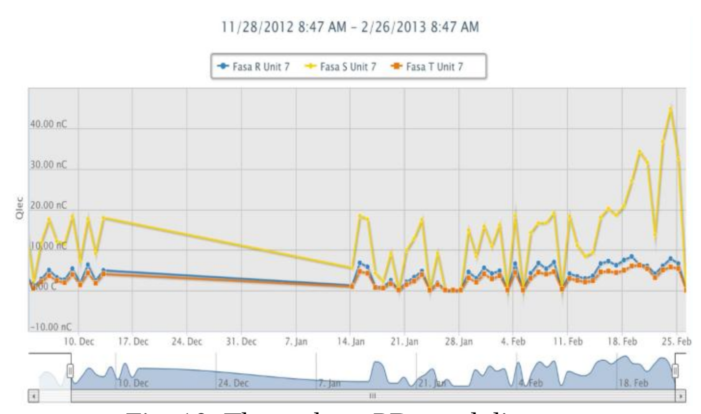


Fig. 10. Three phase PD trend diagram

After the separation, the back transformation to individual PRPD pattern was performed and automated pattern classification was applied. The results indicated advanced delamination of the insulation layers of the stator bars, typical in machines in service for more than 20 years.

PRPD patterns indicating the same type of PD source were discovered in the other phases of the machine. They show a lower PD level either because the delamination stage is less advanced or the PD sources are located deeper inside the windings, therefore subjected to more attenuation.
Similar symptoms of insulation delamination were also observed on the other identical generators in the plant.

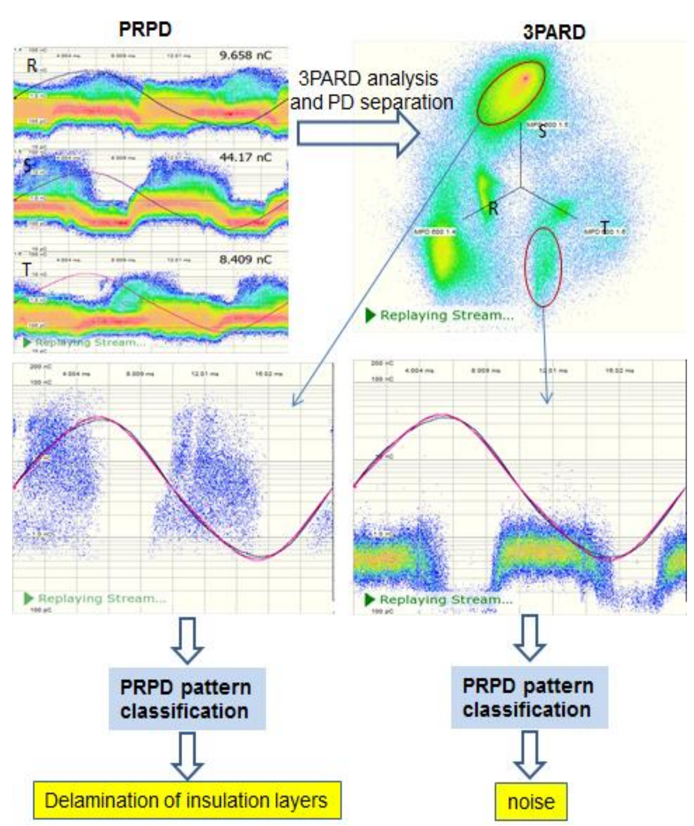


Fig. 11. Advanced post-processing of PD

7 CONCLUSIONS

Continuous PD monitoring is an essential diagnostic tool for condition based maintenance to guarantee high reliability of rotating machines.
The main key to performing appropriate diagnosis of the state of the insulation is to accurately separate different PD sources from external noise and disturbances. To achieve this, synchronous multi-channel evaluation techniques are applied.
In order to identify PD defects, an advanced automated system is proposed and successfully applied.

8 REFERENCIAS

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